Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

150 Years of Maxwell's Equations and Raj Mittra

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Raj Mittra EM Symposium
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Outline

- Introduction and history of electromagnetics
- Three physics of electromagnetics;
- Raj Mittra and Electromagnetics

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A Brief History of Electromagnetics and Optics

- Ampere's Law 1823;
- Faraday Law 1838;
- KCL/KVL 1845

Telegraphy (Morse) 1837;

Electrical machinery (Sturgeon) 1832;

- Snell, 1621;
- Huygens/Newton 1660;
- Fresnel 1814;
- Kirchhoff 1883;
- Maxwell's equations 1864;
- Quantum electrodynamics 1920 (Dirac, Feynman);
- Nano-fabrication technology;
- Single-photon measurement;
- Quantum optics/Nano-optics 1980s;
- Quantum information 1980s;
- Computational quantum electromagnetics (on the horizon).

Electromagnetics (EM) /Optics Technologies

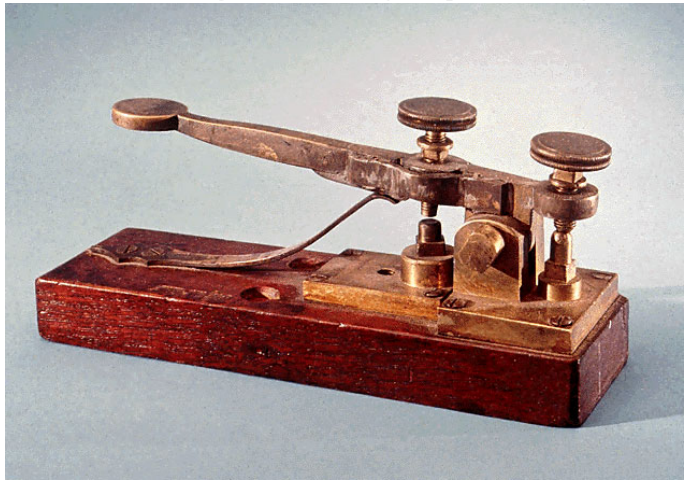
Electromagnetics

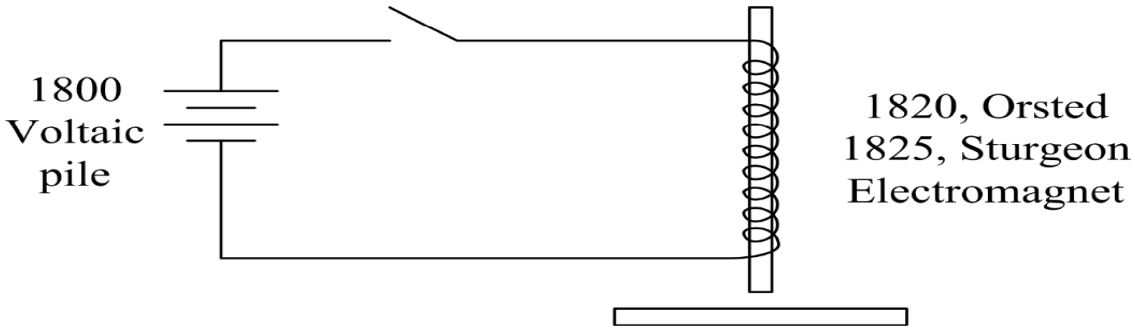
- Antennas;
  - **Communications;**
- Radars;
- Maser (1952);
- Remote sensing;
- Synthetic Aperture Radar;
- Interferometric radar;
- Computational electromagnetics;

Optics

- Lens;
- Lasers (1958);
- Semiconductor lasers;
- LEDs;
- Opto-electronics;
- Interferometric imaging;
  - **Optical Coherence Tomography;**
  - **Optical phase imaging;**
- Nano-optics;
  - **Nano-antennas.**

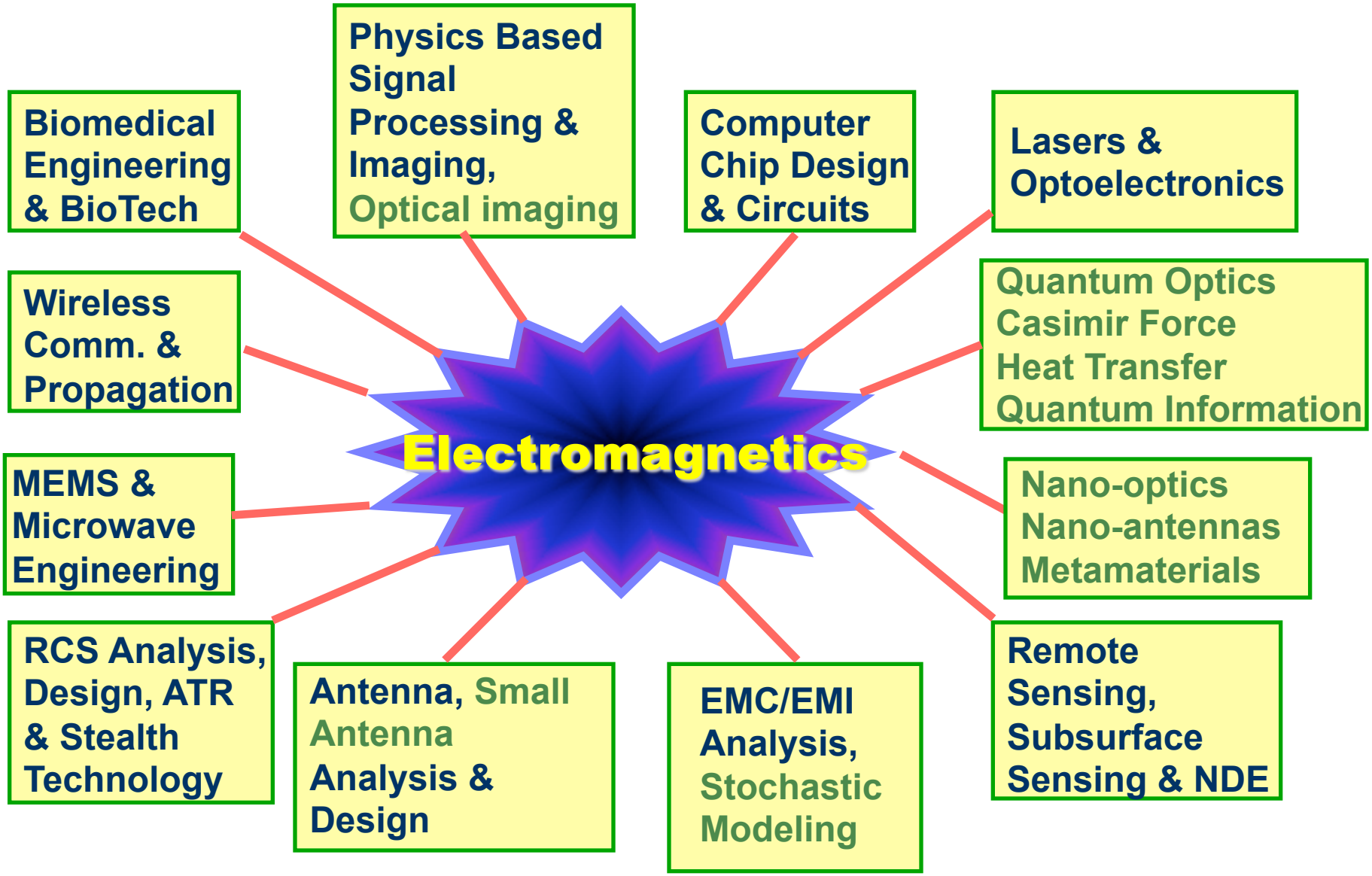
Telegraphy (Early Electromagnetic Technology)





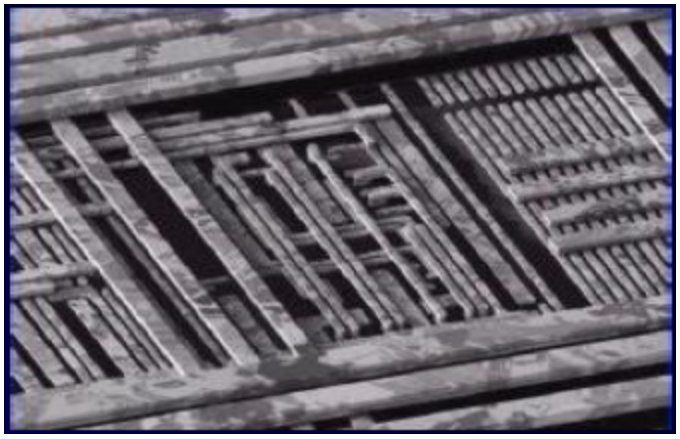
- 1800, Voltaic pile;
- 1820, Orsted, electricity produces magnetic field;
- 1825, Sturgeon, electromagnet;
- 1836, Morse code;
- 1866, Transatlantic marine cable;
- 1871, Cable to India, Singapore, and Hong Kong.

Importance of Electromagnetics and its Enduring Legacy --20 years Later



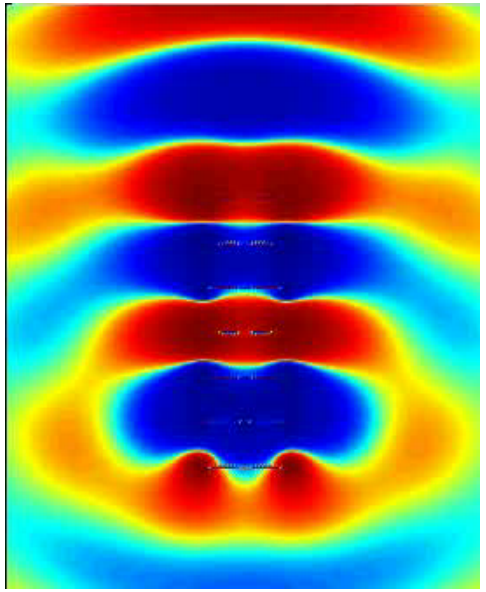
Intro: The Tale of Three Physics; Circuit Physics; Wave Physics; Ray Physics;

Simulated by Zhixiu KOH, '06



Circuit Physics

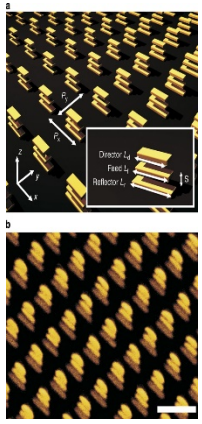
Wave Physics

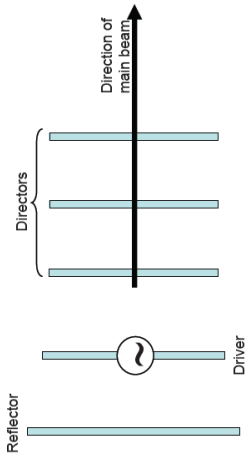


Yagi-Uda 1926

Inspired nano-antennas: Dragely et al.

Ray Physics

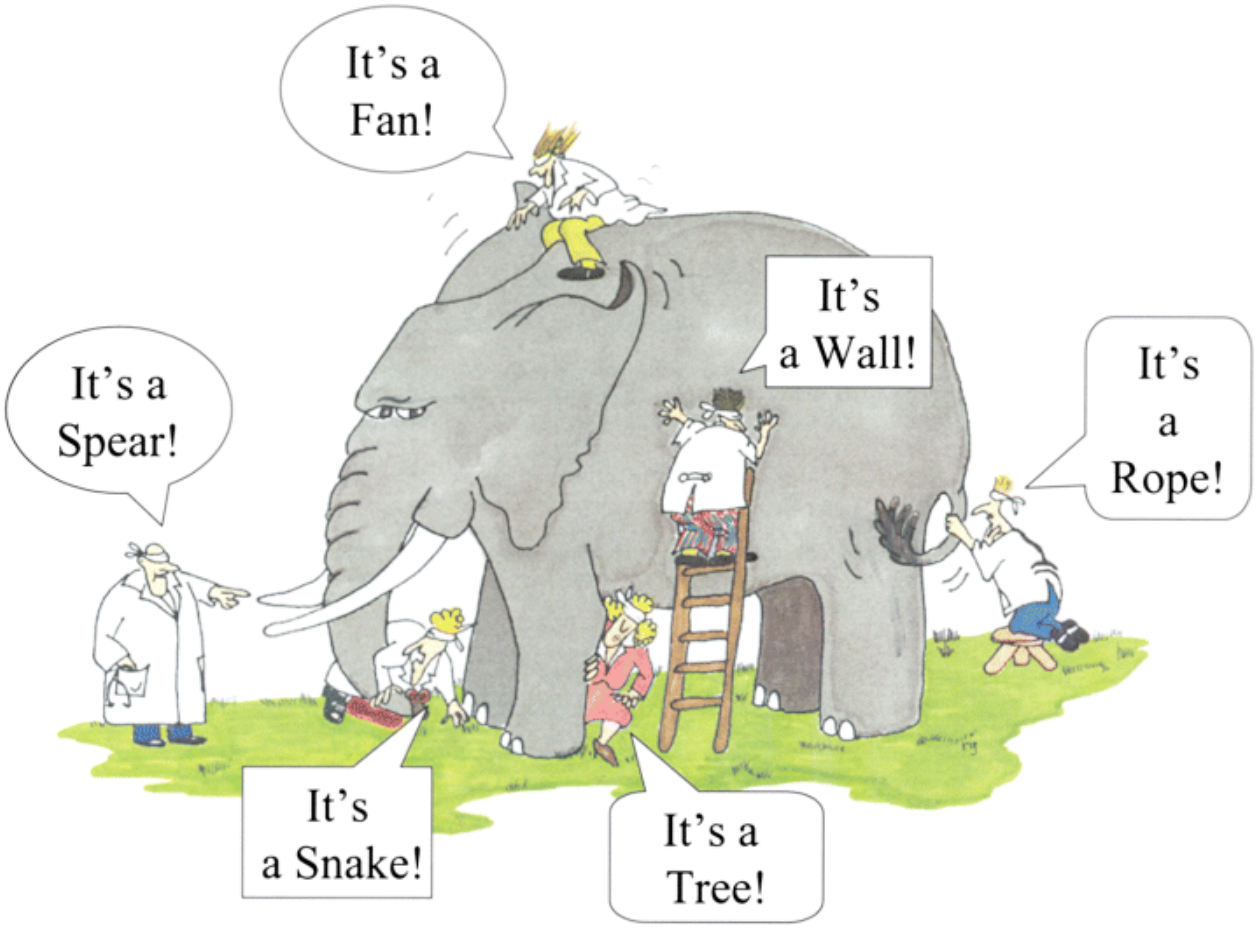




W.C. Chew, Philo. Trans. Royal Soc. London Series A, Math., Phys. Eng. Sci. Theme Issue Short Wave Scattering, vol. 362, no. 1816, pp. 579-602, March 15, 2004.

Famous Indian Proverb

- Raj has done so much, one man can't tell all!



Raj the Great Thesis Supervisor

- 70+ PhD students;
  - **Spread over a diversity of areas in electromagnetics;**
- Great developer of talents;
- Many are giants and entrepreneurs in their fields;
- Reminds me of Arnold Sommerfeld;
  - **Max Born believed Sommerfeld's abilities included the "discovery and development of talents." Albert Einstein told Sommerfeld: "What I especially admire about you is that you have, as it were, pounded out of the soil such a large number of young talents."**

When Did I First Hear of Raj?

- R. Mittra, "An automatic phase measuring circuit at microwaves," IRE Trans. on Instrumentation, vol. 1-6, pp. 238-240, December 1957. (ME at 97)
- In the late 70's… (ME at 108)
- Graduate student at MIT (Kong);
- Itoh and Mittra
  - **Itoh, Tatsuo, and Raj Mittra. "Spectral-domain approach for calculating the dispersion characteristics of microstrip lines (short papers)." *Microwave Theory and Techniques, IEEE Transactions on* 21.7 (1973): 496-499.**
  - **Itoh, Tatsuo, and Raj Mittra. "Analysis of a microstrip disk resonator." *Microwave Conference, 1973. 3rd European*. Vol. 1. IEEE, 1973.**
  - **Itoh, Tatsuo. "Analysis of microstrip resonators." *Microwave Theory and Techniques, IEEE Transactions on* 22.11 (1974): 946-952.**

Excepts:

Spectral-Domain Approach for Calculating the Dispersion Characteristics of Microstrip Lines

TATSUO ITOH AND RAJ MITTRA

***Abstract*—The boundary value problem associated with the open microstrip line structure is formulated in terms of a rigorous, hybird-mode representation. The resulting equations are subsequently transformed, via the application of Galerkin's method in the spectral domain, to yield a characteristic equation for the dispersion properties of the open microstrip line.**

Numerical results are included for several different structural parameters. These are compared with other available data and with some experimental measurements.

$$G_{11}(\alpha,\beta)\tilde{J}_x(\alpha) + G_{12}(\alpha,\beta)\tilde{J}_z(\alpha) = \tilde{U}_1(\alpha) + \tilde{U}_2(\alpha) \qquad (8a)$$

$$G_{21}(\alpha,\beta)\tilde{J}_x(\alpha) + G_{22}(\alpha,\beta)\tilde{J}_z(\alpha) = \tilde{V}_1(\alpha) + \tilde{V}_2(\alpha) \qquad (8b)$$

where

$$\tilde{U}_1(\alpha) = \int_{-\infty}^{-w/2} u(x)e^{j\alpha x}\,dx$$

$$\tilde{U}_2(\alpha) = \int_{w/2}^{\infty} u(x)e^{j\alpha x}\,dx$$

$$\tilde{V}_1(\alpha) = \int_{-\infty}^{-w/2} v(x)e^{j\alpha x}\,dx$$

$$\tilde{V}_2(\alpha) = \int_{w/2}^{\infty} v(x)e^{j\alpha x}\,dx$$

and

$$G_{11} = \frac{1}{\det}\left[F_1 b_{22} + \frac{\alpha\beta}{k_1^2 - \beta^2}\, b_{12}\right]$$

$$G_{12} = \frac{b_{12}}{\det}$$

$$G_{21} = \frac{\gamma_2}{\det}\left[F_1 b_{21} + \frac{\alpha\beta}{k_1^2 - \beta^2}\, b_{11}\right]$$

$$G_{22} = \frac{\gamma_2 b_{11}}{\det}.$$

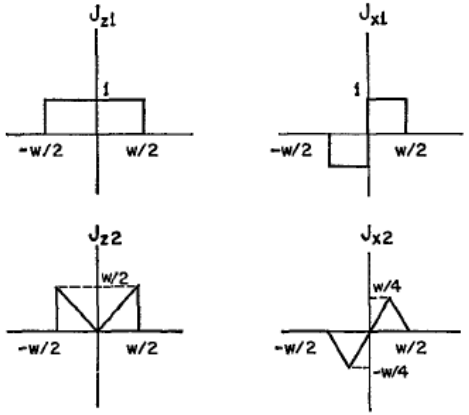


Fig. 2. Basis functions for J_x and J_z.

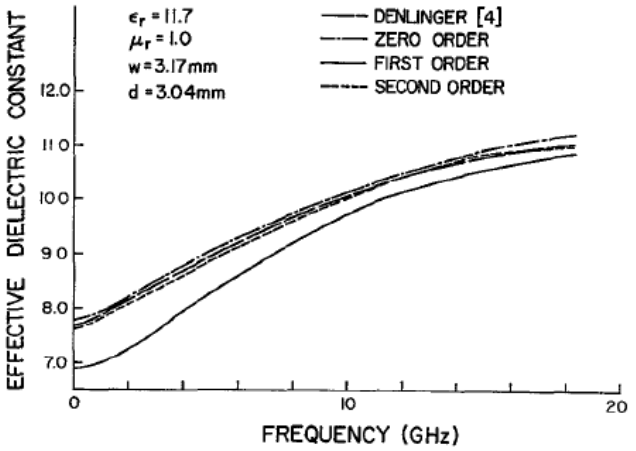


Fig. 3. Effective dielectric constant versus frequency.

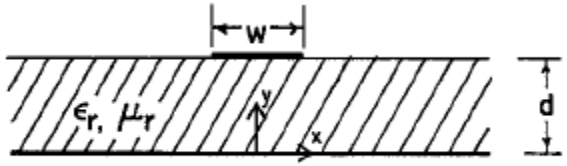


Fig. 1. Microstrip line.

Raj the Innovator (Incomplete List)

- Computational methods for electromagnetics;
  - **A.F. Peterson, SL Ray, etc, 1998**
- Frequency selective surfaces (FSS);
  - **C. Chan, T. Cwik, CH Tsao, 1988, 1984**
- Genetic algorithms;
  - **Sajer, Ranjithan, Michielssen, Boag; 1993, 1996**
- Characteristic basis function method;
  - **Prakash, J. Yeo, 2003**
- Frontiers in EM;
  - **D.H. Werner, 2000**
- Conformal, non-orthogonal FDTD;
  - **S. Dey, J.F. Lee, 1997, 1992**

Raj the Innovator, Contd

- Prony, pole-zero based methods;
  - **WL Ko, Van Blaricum, M. Hurst, 1975, 1987, 1991**
- PML;
  - **Kuzouglu, 1996**
- Periodic boundary condition FSS;
  - **P. Harms, 1994**
- Variational method;
  - **Yamashita, 1968**
- Electromagnetic bandgap structures;
  - **YJ Lee, J. Yeo, WS Park, 2005**
- Closed form Green's function;
  - **Irsadi Aksun, 1992**

Raj the Innovator, Contd

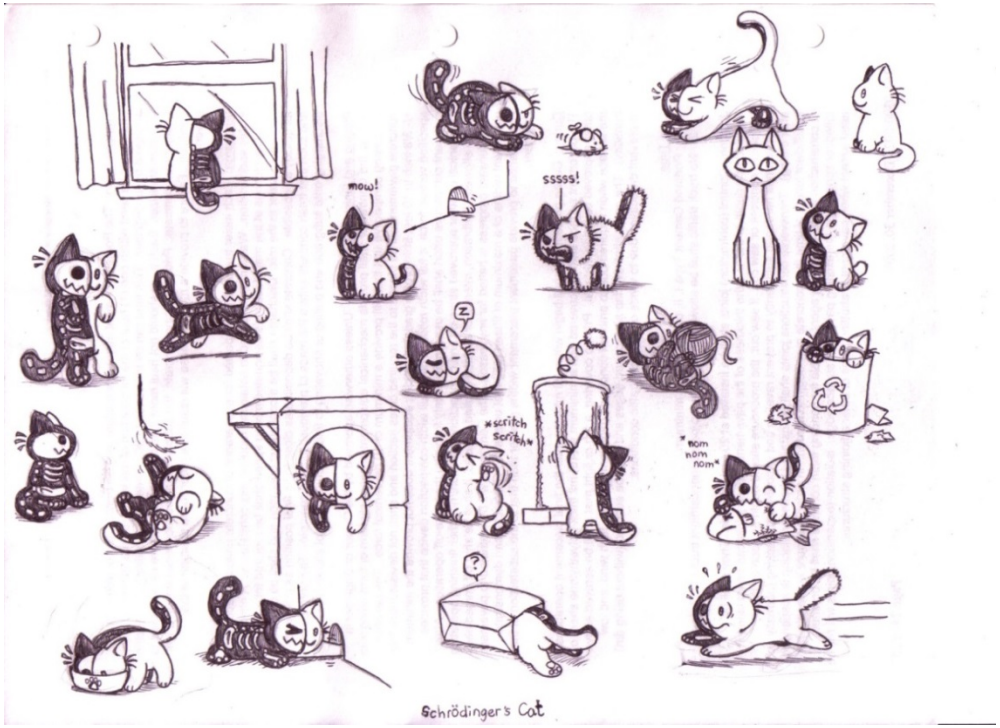
- Parallel FDTD;
  - **W. Yu, T. Su, Y. Liu, S. Yang, 2006**
- Compact microstrip patch antenna;
  - **S. Dey, 1996**
- Spectral domain method;
  - **T. Itoh, 1973**
- Millimeter and optical integrated circuits;
  - **McLevige, 1975**
- Microgenetic algorithm;
  - **S. Chkravarty, 2002**
- Periodic Green's function
  - **R.E. Jorgenson, 1990**
- Other collaborators: Y. Rahmat-Samii, J. Schutt-Aine, S.W. Lee

Raj the Perpetual Mentor

- Raj Mittra travel grant;
- Nominated a large number of IEEE Fellow:
  - **"Dear Prof. Chew, Raj Mittra has agreed to nominate me for IEEE Fellow, can you be one of my referees…"**
- Active and great international collaborator;
  - **Active all over the world;**

Raj the Globe Trotter

- He is all over the place;
- Raj does not fall asleep in conferences and workshops;
- The Quantum Raj;
  - **Schrodinger cat, Schrodinger Raj?**



Raj the Pugilist

- The feud on iterative method and spectral iterative method;
- We all came out to watch!

Another famous Indian proverb: When elephants fight, it's the grass that gets trampled.

Things I Don't Know About Raj

- Does Raj dye his hair?
- How many Rolls Royce does Raj have?
- Is Raj a Brahmin?
- How old is Raj?
- Does Raj have a prurient taste?
- How does Raj keep himself so young?
  -
  -
  -
  -

No amount of snooping can you find these answers!

Raj the Philanthropist

- Raj Mittra travel grant;
- ECEB Classroom, $500K;

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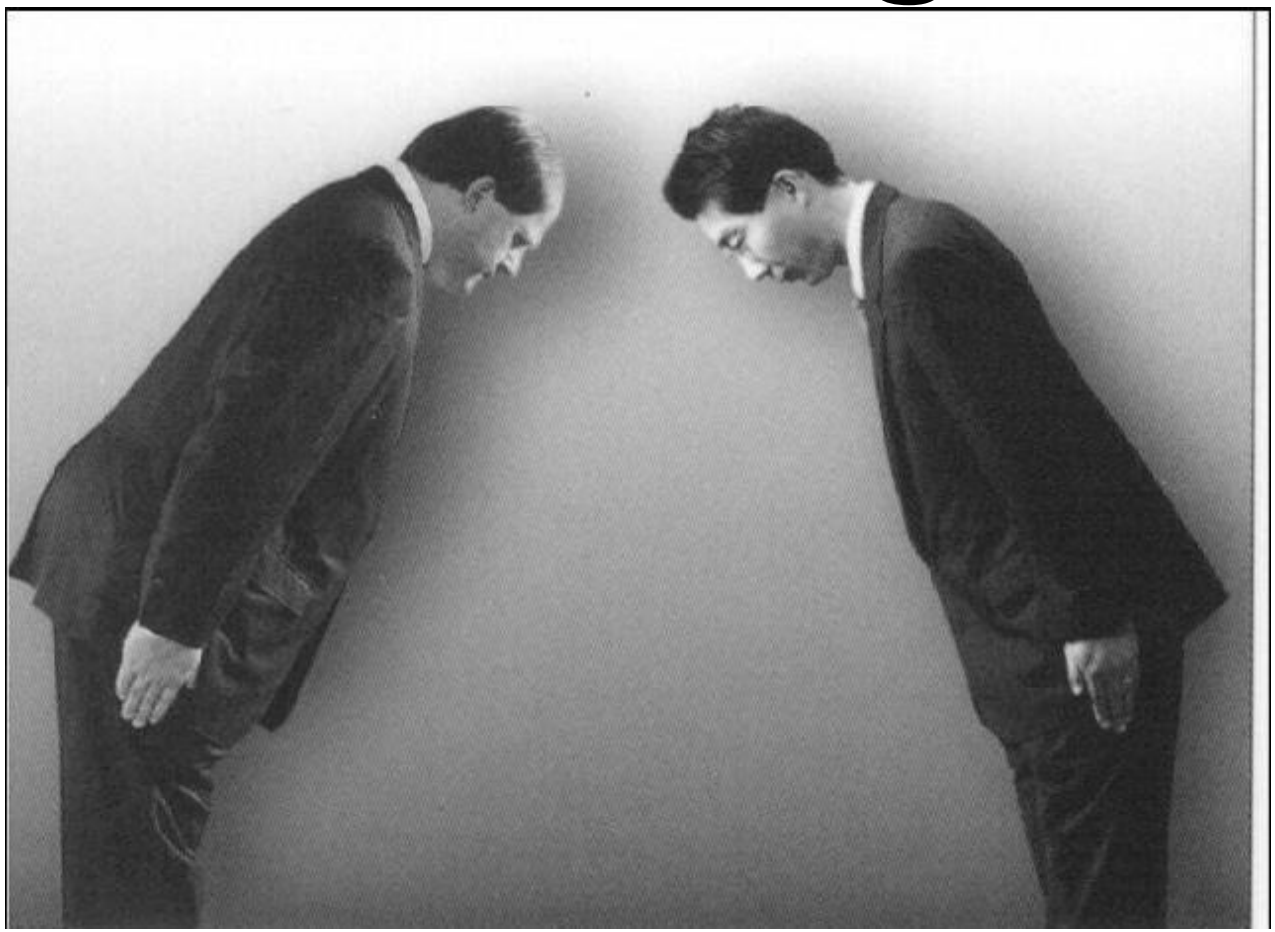
Thank you very much Raj

Thank You for Listening!